Chapter 3. Water Quality

Introduction

The City of San Diego (City) analyzes seawater samples collected along the shoreline and in offshore coastal waters surrounding both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) to characterize water quality conditions in the region and to identify possible impacts of wastewater discharge on the marine environment. Densities of three types of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms and enterococcus are measured and evaluated in context with oceanographic data (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through the PLOO and SBOO. Evaluation of these data may also help to identify other sources of bacterial contamination. Further, the City's water quality monitoring efforts are designed to assess compliance with the water contact standards specified in the 2005 California Ocean Plan (Ocean Plan), which defines bacterial water quality objectives and standards with the intent of protecting the beneficial uses of State ocean waters (SWRCB 2005).

In the PLOO region, multiple natural and anthropogenic point and non-point sources of potential bacterial contamination exist in addition to the outfall. Therefore, being able to separate the impacts associated with a wastewater plume from other sources of contamination in ocean waters is often challenging. Examples of other local, but non-outfall sources include tidal exchange from San Diego Bay, and outflows from the Tijuana and San Diego Rivers and coastal lagoons in northern San Diego County (Nezlin et al. 2007, Svejkovsky 2012). Likewise, storm drain discharges and wet-weather runoff from local watersheds can also flush contaminants seaward (Noble et al. 2003, Reeves et al. 2004, Griffith et al. 2010, Sercu et al. 2009). Moreover, beach wrack (e.g., kelp, seagrass), storm drains impacted by tidal flushing, and beach sediments can act as reservoirs, cultivating bacteria until release into nearshore waters by a returning tide, rainfall, and/or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). The presence of birds and their droppings have also been associated with bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

This chapter presents analyses and interpretations of the microbiological and water chemistry data collected during 2011 at fixed water quality monitoring stations surrounding the PLOO. The primary goals are to: (1) document overall water quality conditions in the region during the year, (2) distinguish between the PLOO wastewater plume and other sources of bacterial contamination, (3) evaluate potential movement and dispersal of the plume, and (4) assess compliance with water contact standards defined in the 2005 Ocean Plan.

Materials and Methods

Field Sampling

Shore stations

Seawater samples were collected at eight shore stations (i.e., stations D4, D5, and D7–D12; Figure 3.1) to monitor concentrations of total coliform, fecal coliform and enterococcus bacteria in waters adjacent to public beaches and to evaluate compliance with 2005 Ocean Plan water contact standards (see Box 3.1). These samples were collected from the surf zone in sterile 250-mL bottles at each station five times per month. Visual observations of water color, surf height, human or animal activity, and weather conditions were also recorded at the time of collection. The samples were then transported on blue ice to the City's Marine Microbiology Laboratory for analysis.

Kelp bed and offshore stations

Eight stations located in nearshore waters within the Point Loma kelp forest were sampled weekly

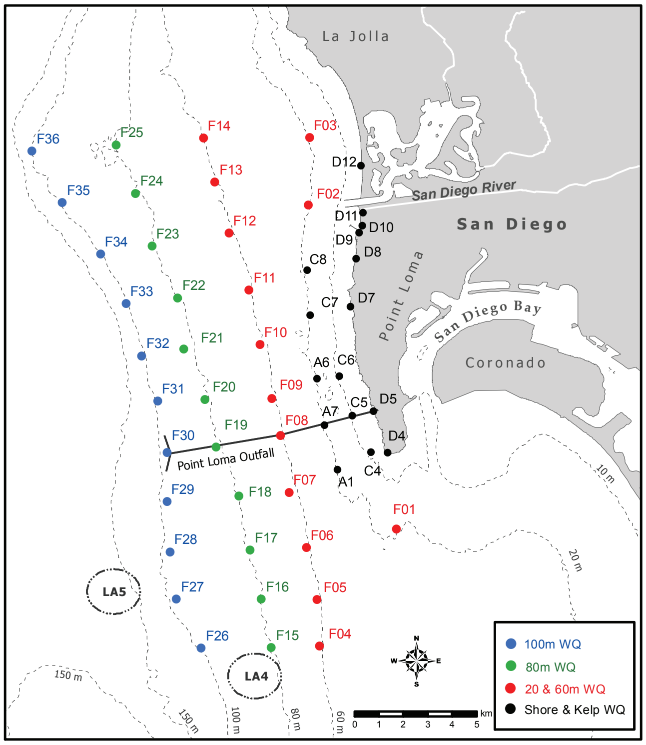


Figure 3.1
Water quality (WQ) monitoring station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

to assess water quality conditions and Ocean Plan compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These included stations C4, C5 and C6 located near the inner edge of the kelp bed along the 9-m depth contour and stations A1, A6, A7, C7 and C8 located near the outer edge of the kelp bed along the 18-m depth contour (Figure 3.1). Weekly monitoring at each of the kelp bed sites consisted of collecting seawater samples to determine concentrations of the same fecal indicator bacteria as at the shore stations. Additional samples to assess ammonia levels were collected quarterly at these kelp sites to correspond with offshore water quality sampling schedule described below.

An additional 36 stations located offshore of the kelp bed stations were sampled in order to monitor FIB levels in these deeper waters and to estimate dispersion of the wastewater plume. These offshore "F" stations are arranged in a grid surrounding the discharge site along or adjacent to the 18, 60, 80, and 98-m depth contours (Figure 3.1). In contrast to shore and kelp bed stations, monitoring at the offshore stations was conducted on a quarterly basis during February, May, August and November; each of these quarterly surveys was conducted over a 3-day period (see Table 2.1 for the specific survey dates). Bacterial analyses for these samples were limited to enterococcus. Additional monitoring for ammonia occurred at the same discrete depths where bacterial samples were collected at the 15 offshore stations located within State jurisdictional waters (i.e., within 3 nautical miles of shore).

Seawater samples for the kelp and offshore stations were collected at 3, 4 or 5 discrete depths depending upon station depth (Table 3.1). These samples were collected using either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles. Aliquots for ammonia and bacteriological analyses were drawn into sterile sample bottles and refrigerated prior to processing at the City's Toxicology and Marine Microbiology Laboratories, respectively. Visual observations of weather and sea conditions, and human and/or animal activity were also recorded at the time of sampling.

Laboratory Analyses

The City's Microbiology Lab follows guidelines issued by the United States Environmental Protection Agency (USEPA) Water Quality Office and the California Department of Public Health (CDPH) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1995, CDPH 2000, USEPA 2006). All bacterial analyses were performed within eight hours of sample collection and conformed to standard membrane filtration techniques (APHA 1995).

Enumeration of FIB densities was performed and validated in accordance with USEPA (Bordner et al. 1978, USEPA 2006) and APHA (1995) guidelines. Plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating

Box 3.1

Bacteriological compliance standards for water contact areas, 2005 California Ocean Plan (SWRCB 2005). CFU = colony forming units.

(a) *30-day Geometric Mean* – The following standards are based on the geometric mean of the five most recent samples from each site:
1) Total coliform density shall not exceed 1000 CFU/100 mL.
2) Fecal coliform density shall not exceed 200 CFU/100 mL.
3) Enterococcus density shall not exceed 35 CFU/100 mL.

(b) *Single Sample Maximum*:
1) Total coliform density shall not exceed 10,000 CFU/100 mL.
2) Fecal coliform density shall not exceed 400 CFU/100 mL.
3) Enterococcus density shall not exceed 104 CFU/100 mL.
4) Total coliform density shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform ratio exceeds 0.1.

means and in determining compliance with Ocean Plan standards.

Quality assurance tests were performed routinely on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported under separate cover (City of San Diego 2012a).

Additional seawater samples were analyzed by the City's Toxicology Lab to determine ammonia (as nitrogen) concentrations using a Hach DR850 colorimeter and the Salicylate Method (Bower and Holm-Hansen 1980). Quality assurance tests for these analyses were performed using blanks.

Data Analyses

FIB densities were summarized as monthly averages for each shore station and by depth contour for each of the kelp bed stations. To evaluate any spatial or temporal trends, the data were summarized as the number of samples in which FIB concentrations exceeded benchmark levels. For this report, the Single Sample Maximum (SSM) values defined in the 2005 Ocean Plan for total coliforms, fecal coliforms, and enterococcus (see Box 3.1 herein, and SWRCB 2005) were used as the benchmarks to distinguish elevated FIB values. Concentrations of each elevated FIB are identified by sample in Table 3.2. Bacterial densities were compared to rain data from Lindbergh Field, San Diego, CA (see NOAA 2012). Fisher's Exact Tests (FET) were used for historical analyses to test for differences in the frequency of samples with elevated FIBs. Finally, compliance with Ocean Plan water-contact standards was summarized as the number of times per month that each of the shore and kelp bed stations exceeded the various standards.

Results

Distribution of Fecal Indicator Bacteria

Shore stations

Concentrations of fecal indicator bacteria (FIB) were generally low along the Point Loma shoreline in 2011, which is similar to conditions seen in previous years. Monthly FIB densities at the individual stations averaged 6–1292 CFU/100 mL for total coliforms, 2–178 CFU/100 mL for fecal coliforms, and 2–49 CFU/100 mL for enterococcus (Appendix B.1). Of the 486 shore samples collected during the year, only three (0.6%) had elevated FIBs (Table 3.2). These included one sample from station D8 in January, one sample from station D5 in April, and one sample from station D9 in June. The total number of elevated FIB samples was much lower in 2011 than has been reported in previous years (Figure 3.2, Appendix B.2). This historical comparison also illustrates that chances of getting FIB hits in the wet season were only slightly

Table 3.1

Depths at which seawater samples are collected for bacteriological analysis at the PLOO kelp bed and offshore stations.

Station Contour	Sample Depth (m) 1	3	9	12	18	25	60	80	98
Kelp Bed									
9-m	x	x	x						
18-m	x			x	x				
Offshore									
18-m	x			x	x				
60-m	x					x	x		
80-m	x					x	x	x	
98-m	x					x	x	x	x

more likely than in the dry season (7% versus 2%, respectively; $n = 6686$, $p < 0.0001$, FET).

Kelp bed stations

FIB concentrations were also generally low at the eight kelp bed stations during 2011. Monthly densities averaged 4–37 CFU/100 mL for total coliforms, 2–4 CFU/100 mL for fecal coliforms, and 2–15 CFU/100 mL for enterococcus (Table 3.3). Only a single sample collected in the Point Loma kelp forest during the entire year (~0.07%; $n = 1437$) had elevated FIBs (Table 3.2). The low incidence of elevated FIBs at these sites is consistent with water quality results dating back to 1994 after the outfall was extended offshore to its present deepwater site (Figure 3.3, Appendix B.3). In contrast, bacteria levels were much higher at the kelp bed stations prior to the outfall extension. No relationship between rainfall and elevated bacterial levels was evident at these stations, in that the chances of getting FIB hits was similar between wet and dry seasons (~4% for both).

Offshore stations

The maximum concentration of enterococcus bacteria at the 36 offshore stations was 660 CFU/100 mL in 2011 (Table 3.2). Only 6 of 548 samples (1.1%) had elevated enterococcus levels, all of which were collected at depths ≥60 m from four stations located along the 80 and 98-m depth contours (Figure 3.4). No exceedances occurred within State waters. These results suggest that the wastewater plume remained restricted to relatively deep, offshore waters throughout the year. This conclusion is consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2011 (Svejkovsky 2012). These findings are also consistent with historical

Table 3.2

Summary of elevated bacteria densities in samples collected at PLOO shore, kelp bed, and offshore stations during 2011. Bold values exceed benchmarks for total coliform, fecal coliform, enterococcus, and/or the FTR criterion.

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
Shore Stations						
D8	3 Jan 2011	—	1600	160	**200**	0.10
D5	21 Apr 2011	—	1300	**880**	**180**	**0.68**
D9	2 Jun 2011	—	920	**580**	56	0.63
Kelp Bed Stations						
A1	13 Apr 2011	12	10	2	**880**	0.20
Offshore Stations						
F30	10 Feb 2011	80	—	—	**660**	—
F30	10 Feb 2011	98	—	—	**110**	—
F31	10 Feb 2011	80	—	—	**160**	—
F30	6 May 2011	80	—	—	**380**	—
F16	17 Aug 2011	60	—	—	**380**	—
F17	17 Aug 2011	60	—	—	**420**	—

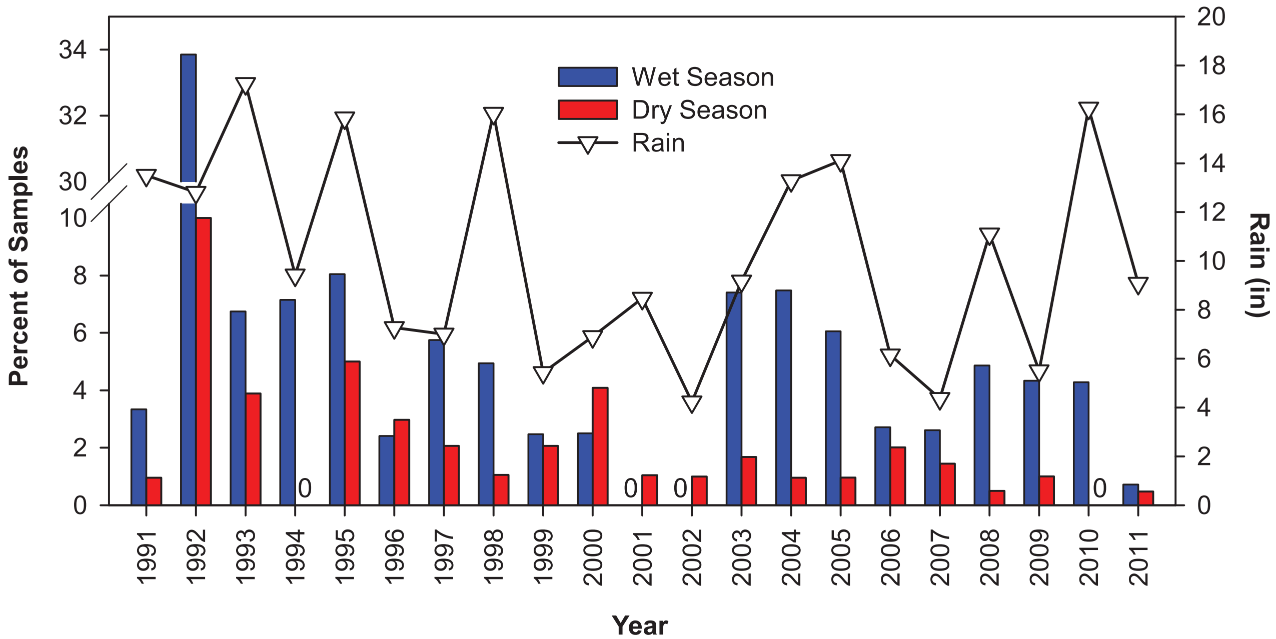


Figure 3.2

Comparison of annual rainfall to the percent of samples with elevated FIB denities in wet versus dry seasons at PLOO shore stations between 1991 and 2011. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA.

analyses, which revealed that less than 1% of the samples collected from ≥25 m at the eleven 98-m PLOO stations between 1993 and 2011 contained elevated levels of enterococcus (Figure 3.5A). Over this time period, collecting a sample with elevated FIBs was significantly more likely at station F30 than at any other 98-m station (23.7% versus 6.6%, respectively; $n = 5133$, $p < 0.0001$, FET; Figure 3.5B). Additionally, the number of samples with elevated enterococcus dropped significantly at most 98-m stations following the initiation of chlorination in August 2008 (7.5% before versus 1.7% after; $n = 4415$, $p < 0.0001$, FET), but not at station F30 (24.0% before versus 20.0% after, $n = 718$, $p < 0.542$, FET).

California Ocean Plan Compliance

Overall compliance with the seven Ocean Plan standards was 99.8% during 2011 (see Appendix B.4). Shoreline compliance with the three 30-day geometric means standards was 100% for total and fecal coliforms, and 95–100% for enterococcus (Appendix B.4). The only exeedances of the enterococcus geometric mean standard occurred during January at stations D8, D10 and D11. Compliance with the four single sample maximum (SSM) standards was also very high (>98%) for each of the shore stations during the year. The SSM for total coliforms was not exceeded, while the SSMs for fecal coliforms and enterococcus were each exceeded twice, and the SSM for the FTR criterion was exceeded only once. Only one of the Ocean Plan standards was exceeded at the kelp stations (i.e., the enterococcus SSM at station A1 in April). Finally, all of the offshore stations located within State waters were 100% compliant during 2011; these stations are not sampled frequently enough for appropriate geometric mean assessments.

Samples were analyzed for ammonia at the eight kelp stations and 15 other offshore stations located within State waters. Ammonia was detected in 12% of the 288 samples collected from 14 of these stations during 2011. No ammonia was detected at any of the 9-m depth sites, while concentrations at the 18-m, 60-m, and 80-m sites ranged up to a maximum of 0.26 mg/L (Table 3.4). These levels are substantially lower than the water quality objectives for ammonia defined in the Ocean Plan (i.e., instant maximum of 6.0 mg/L, daily maximum of 2.4 mg/L;

Table 3.3

Summary of bacteria levels at PLOO water quality stations during 2011. Total coliform, fecal coliform, and enterococcus densities are expressed as mean CFU/100 mL for all stations along each depth contour by month. Rain data are from Lindbergh Field, San Diego, CA. *n* = total number of samples per month.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011 Total Rain (in)	0.30	2.10	1.46	0.26	0.36	0.03	0.00	0.00	0.13	0.46	3.12	0.86
Shore Stations (*n* = 40) [a]												
Total	81	376	102	234	41	59	82	63	74	111	109	56
Fecal	12	20	8	29	4	19	10	9	8	22	10	5
Entero	11	10	6	8	3	6	5	4	4	17	8	3
Kelp Bed Stations (*n* = 45)												
9-m Contour												
Total	8	4	23	6	9	4	7	4	5	5	4	5
Fecal	2	2	3	2	2	2	2	2	2	2	2	2
Entero	2	3	2	2	2	2	2	2	2	2	2	2
18-m Contour												
Total	10	12	37	12	11	4	24	8	8	5	11	4
Fecal	2	2	2	2	2	2	4	2	2	2	3	2
Entero	2	2	2	15	2	3	2	2	2	2	3	2
Offshore Stations [b]												
18-m Contour (*n* = 9)	—	2	—	—	2	—	—	2	—	—	2	—
60-m Contour (*n* = 33)	—	4	—	—	2	—	—	4	—	—	2	—
80-m Contour (*n* = 40)	—	6	—	—	4	—	—	30	—	—	5	—
98-m Contour (*n* = 55)	—	23	—	—	13	—	—	7	—	—	5	—

[a] February and October *n* = 39; July *n* = 48. [b] Enterococcus only

SWRCB 2005). None of the samples where ammonia was detected had elevated concentrations of enterococcus bacteria (see City of San Diego 2012b).

Discussion

Water quality conditions in the Point Loma outfall region were excellent during 2011. Overall compliance with 2005 Ocean Plan water-contact standards was 99.8%, which was only marginally higher than the 99.7% compliance observed during the previous year (City of San Diego 2011). In addition, there was no evidence during the year that wastewater discharged into the ocean via the PLOO reached the shoreline or nearshore recreational waters. Elevated FIBs were detected at only four shoreline or kelp bed stations during the year. Over the years, elevated FIBs detected at shore and kelp bed stations have tended to be associated with rainfall events, heavy recreational use, or the presence of seabirds or decaying kelp and surfgrass (e.g., City of San Diego 2009–2011). The main exception to this pattern occurred during a short period in 1992 following a catastrophic break of the outfall within the Point Loma kelp bed (e.g., Tegner et al. 1995).

Previous reports have indicated that the PLOO wastefield typically remains well offshore and submerged in deep waters ever since the extension of the outfall was completed in late 1993 (e.g., City of San Diego 2007–2011). This pattern remained true for 2011 with evidence that the wastewater plume was restricted to depths of 60 m or below in offshore waters. Moreover, no visual evidence of the plume surfacing was detected in satellite imagery during 2011 (Svejkovsky 2012). The deepwater (98-m) location of the discharge site may be the dominant factor that inhibits the plume from reaching surface

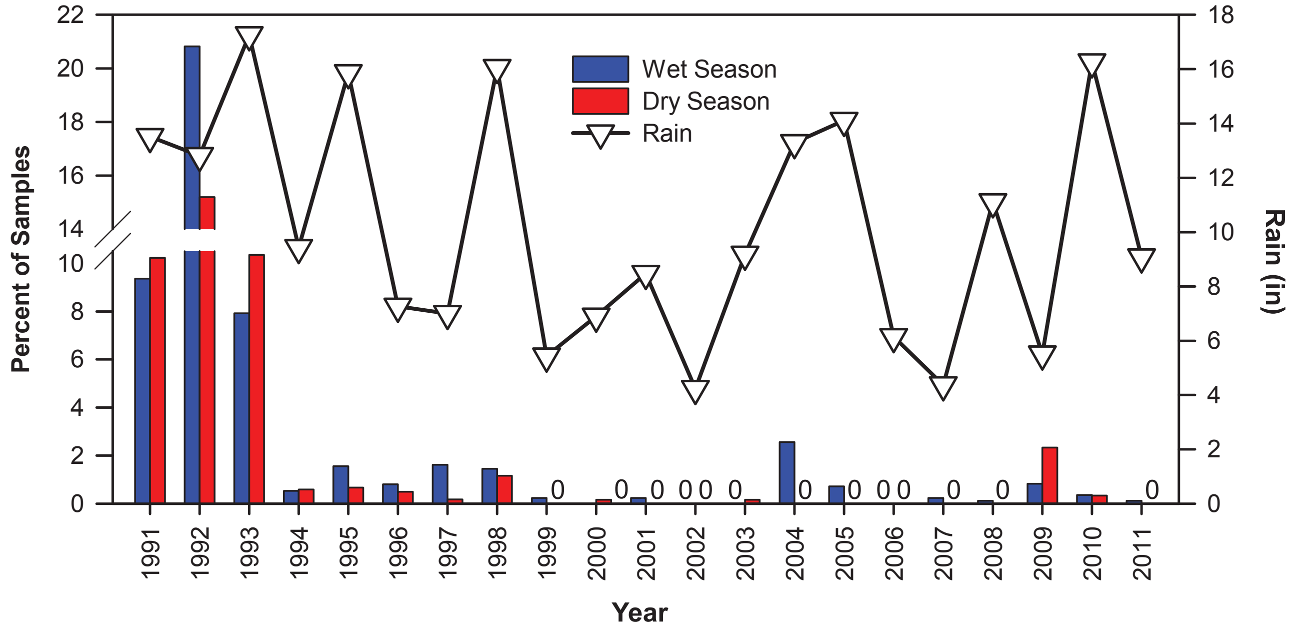


Figure 3.3
Comparison of annual rainfall to the percent of samples with elevated FIB denities in wet versus dry seasons at PLOO kelp bed stations bewteen 1991 and 2011. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA.

waters. For example, wastewater released into these deep, cold and dense waters does not appear to mix with the top 25 m of the water column (see Chapter 2). Finally, it appears that not only is the plume from the PLOO being trapped below the thermocline, but now that effluent is undergoing chlorination prior to discharge, densities of indicator bacteria have dropped significantly at stations more than 1000 m from the outfall.

Literature Cited

[APHA] American Public Health Association. (1995). Standard Methods for the Examination of Water and Wastewater, 19th edition. A.E. Greenberg, L.S. Clesceri, and A.D. Eaton (eds.). American Public Health Association, American Water Works Association, and Water Pollution Control Federation.

Bordner, R., J. Winter, and P. Scarpino, eds. (1978). Microbiological Methods for Monitoring the Environment: Water and Wastes, EPA Research and Development, EPA-600/8-78-017.

Bower, C. E., and T. Holm-Hansen. (1980). A Salicylate-Hypochlorite Method for Determining Ammonia in Seawater. Canadian Journal of Fisheries and Aquatic Sciences, 37: 794–798.

[CDPH] California State Department of Health Services. (2000). Regulations for Public Beaches and Ocean Water-Contact Sports Areas. Appendix A: Assembly Bill 411, Statutes of 1997, Chapter 765. http://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Beaches/APPENDIXA.pdf.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2007. City of San Diego Ocean Monitoring Program, Metropolitan

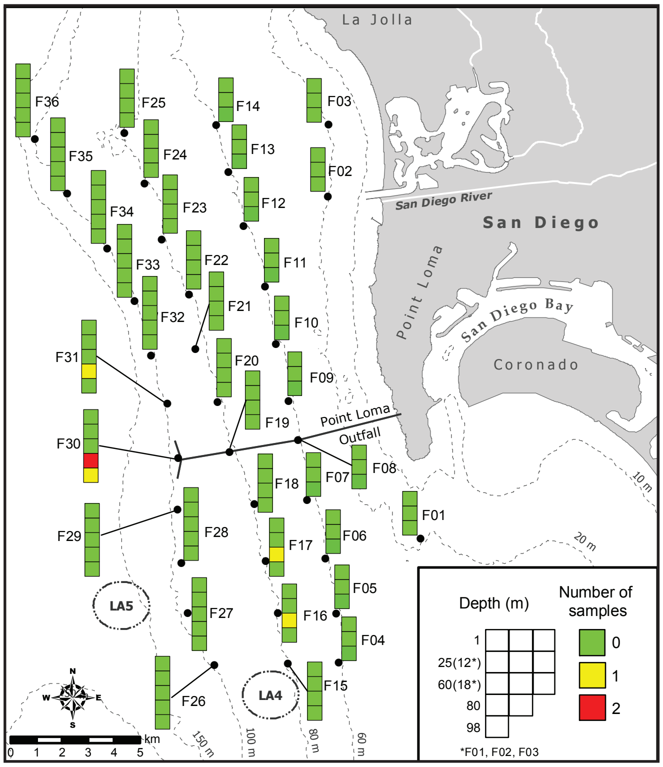


Figure 3.4

Distribution of seawater samples with elevated enterococcus densities at offshore stations during 2011. Data are numbers of samples that exceeded concentrations > 104 CFU/100 mL. See text and Table 2.1 for sampling details.

Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012a). Annual Receiving Waters Monitoring and Toxicity Testing Quality Assurance Report, 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

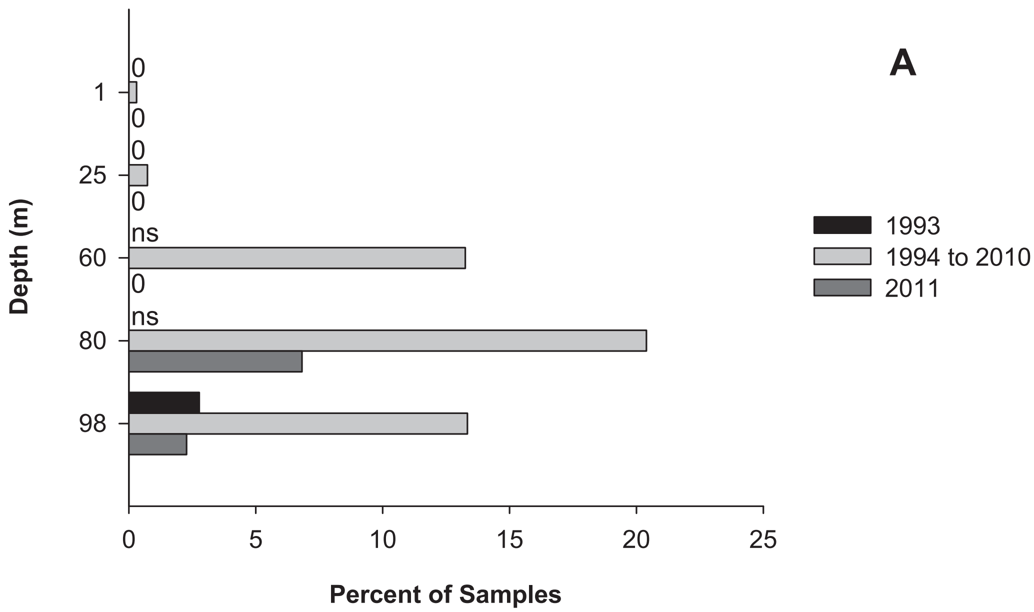
City of San Diego. (2012b). Monthly receiving waters monitoring reports for the Point Loma Ocean Outfall, January–December 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Grant, S., B. Sanders, A. Boehm, J. Redman, R. Kim, A. Chu, M. Gouldin, C. McGee, N. Gardiner, B. Jones, J. Svejkovsky, and G. Leipzig. (2001). Generation of enterococci bacteria in a costal saltwater marsh and its impact on surf zone water quality. Environmental Science Technology, 35: 2407–2416.

Griffith, J., K. Schiff, G. Lyon, and J. Fuhrman. (2010). Microbiological water quality at non-human influenced reference beaches in southern California during wet weather. Marine Pollution Bulletin, 60: 500–508.

Gruber, S., L. Aumand, and A. Martin. (2005) Sediments as a reservoir of indicator bacteria in a coastal embayment: Mission Bay, California, Technical paper 0506. Westin Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005.

Martin, A. and S. Gruber. (2005). Amplification of indicator bacteria in organic debris on southern California beaches. Technical Paper 0507. Weston Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005.



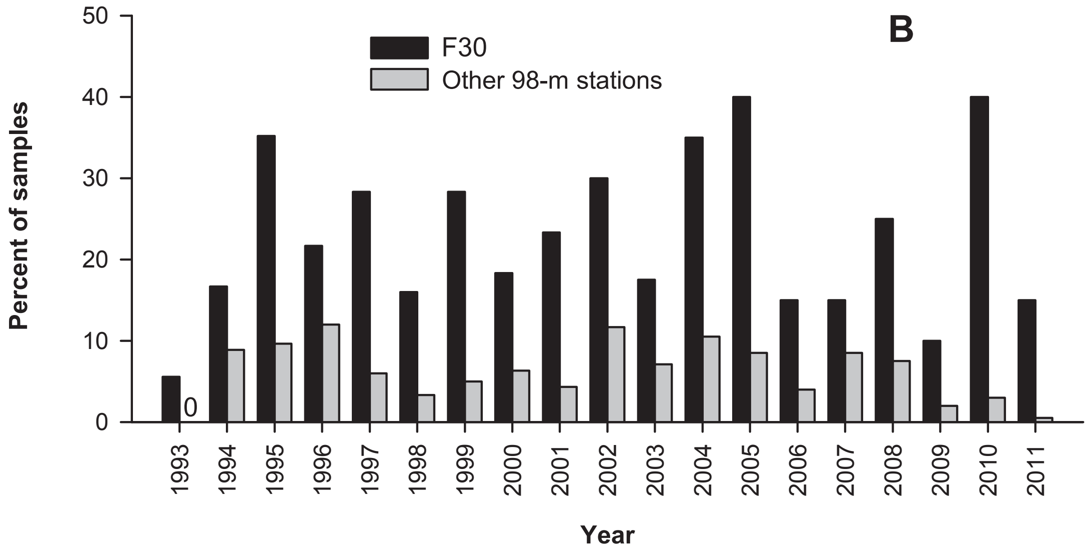


Figure 3.5
Percent of samples collected from PLOO 98-m offshore stations with elevated enterococcus densities. Samples from 2011 are compared to samples taken between 1993–2010 by (A) sampling depth and by (B) outfall (F30) and other non-outfall stations. Depth data are limited to current sample depths. ns = not sampled.

Nezlin, N.P., P.M. DiGiacomo, S.B. Weisberg, D.W. Diehl, J.A. Warrick, M.J. Mengel, B.H. Jones, K.M. Reifel, S.C. Johnson, J.C. Ohlmann, L. Washburn, and E.J. Terrill. (2007). Southern California Bight 2003 Regional Monitoring Program: V. Water Quality. Southern California Coastal Water Research Project. Costa Mesa, CA.

[NOAA] National Oceanic and Atmospheric Administration. (2012). National Climatic Data Center. http://www7.ncdc.noaa.gov/CDO/cdo.

Noble, R.T., D.F. Moore, M.K. Leecaster, C.D. McGee, and S.B. Weisberg. (2003). Comparison of total coliform, fecal coliform, and enterococcus bacterial indicator response for ocean recreational water quality testing. Water Research, 37: 1637–1643.

Noble, M.A., J.P. Xu, G.L. Robertson, and K.L. Rosenfeld. (2006). Distribution and sources of surfzone bacteria at Huntington Beach before and after disinfection of an ocean

Table 3.4
Summary of ammonia concentrations in samples collected from the 23 PLOO kelp bed and offshore stations located within State waters during 2011. Data include the number of samples per month (*n*) and detection rate, as well as the minimum, maximum, and mean detected concentrations for each month. The method detection limit for ammonia = 0.01 mg/L.

	Feb	May	Aug	Nov
9-m Depth Contour (n = 9)				
Detection Rate (%)	0	0	0	0
Min	—	—	—	—
Max	—	—	—	—
Mean	—	—	—	—
18-m Depth Contour (n = 24)				
Detection Rate (%)	8.3	12.5	20.8	0
Min	nd	nd	nd	—
Max	0.03	0.06	0.06	—
Mean	0.02	0.04	0.03	—
60-m Depth Contour (n = 27)				
Detection Rate (%)	0	11.1	18.5	37.0
Min	—	nd	nd	nd
Max	—	0.02	0.03	0.13
Mean	—	0.01	0.02	0.04
80-m Depth Contour (n = 12)				
Detection Rate (%)	0	0	0	58.3
Min	—	—	—	nd
Max	—	—	—	0.26
Mean	—	—	—	0.08

nd = not detected

outfall–A frequency-domain analysis. Marine Environmental Research, 61: 494–510.

Phillips, C.P., H.M. Solo-Gabriele, A.J.H.M. Reneiers, J.D. Wang, R.T. Kiger, and N. Abdel-Mottaleb. (2011). Pore water transport of enterococci out of beach sediments. Marine Pollution Bulletin, 62: 2293–2298.

Reeves, R.L., S.B. Grant, R.D. Mrse, C.M. Copil Oancea, B.F. Sanders, and A.B. Boehm. (2004). Scaling and management of fecal indicator bacteria in runoff from a coastal urban watershed in southern California. Environmental Science and Technology, 38: 2637–2648.

Sercu, B., L.C. Van de Werfhorst, J. Murray, and P.A. Holden. (2009). Storm drains are sources of human fecal pollution during dry weather in three urban southern California watersheds. Environmental Science and Technology, 43: 293–298.

Svejkovsky, J. (2012). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/ Tijuana Region: Annual Summary Report, 1 January, 2011–31 December, 2011. Ocean Imaging, Solana Beach, CA.

[SWRCB] California State Water Resources Control Board. (2005). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.

Tegner, M.J., P.K. Dayton, P.B. Edwards, K.L. Riser, D.B. Chadwick, T.A. Dean, and L. Deysher. (1995). Effects of a large sewage spill on a kelp forest community: Catastrophe or disturbance? Marine Environmental Research, 40: 181–224.

[USEPA] United States Environmental Protection Agency. (2006). Method 1600: Enterococci in Water by Membrane Filtration Using membrane-Enterococcus Indoxyl-β-D-Glucoside Agar (mEI). EPA Document EPA-821-R-06-009. Office of Water (4303T), Washington, DC.

Yamahara, K.M., B.A. Layton, A.E. Santoro, and A.B. Boehm. (2007). Beach sands along the California coast are diffuse sources of fecal bacteria to coastal waters. Environmental Science and Technology, 41: 4515–4521.